Sustainable Production and Consumption 28 (2021) 1333–1342

Contents lists available at ScienceDirect

Sustainable Production and Consumption

journal homepage: www.elsevier.com/locate/spc

Impact of cap-and-trade mechanisms on investments in renewable energy and marketing effort

Chen Wei[a], Zhang Li-Feng[b,*], Du Hong-Yan[c]

[a] *College of Management Science, Chengdu University of Technology, Chengdu 610059, China*
[b] *School of Mathematics, Chengdu Normal University, Chengdu, 611130, China*
[c] *School of Economics, Southwest Minzhu University, Chengdu, 610041, China*

ARTICLE INFO

Article history:
Received 21 March 2021
Revised 27 July 2021
Accepted 16 August 2021
Available online 20 August 2021

Editor: Prof. Urgr Sorytas

Keywords:
Grandfathering mechanism
Benchmarking mechanism
Renewable energy investment
Marketing effort

ABSTRACT

This paper discusses the impact of cap-and-trade mechanisms, including grandfathering and benchmarking mechanisms, on renewable energy investments and marketing efforts in the electricity market. The current system constructs a two-level electricity supply chain, with a leader's electricity generator and a follower's electricity retailer. Based on the analysis framework of the game theory, the optimal solutions under the grandfathering mechanism and benchmarking mechanism are compared. The results are as follows. First, grandfathering and benchmarking are both conducive to the investment of renewable energy. Further, the benchmarking mechanism is more conducive to investments. Second, benchmarking is beneficial to marketing efforts, while grandfathering is not. Third, the grandfathering mechanism and benchmarking mechanism are conducive to the improvement of market demands. Further, grandfathering produces more total carbon emissions, while benchmarking reduces the total carbon emissions.

1. Introduction

In the 2005 reform of China's electricity market, the separation of the electricity generator and electricity retailer emerged (Fang et al., 2018). This mode divides the functions of the electricity generator and electricity retailer. The electricity generator only focuses on electricity production, and the electricity retailer only focuses on electricity sales, which inevitably leads to each party attempting to maximize their profits. Moreover, the China Datang corporation, as one of the five largest power generation companies in China, can be regarded as a leader. Further, the Sichuan Nengtou electricity sales company buying electricity from the China Datang corporation is regarded as a follower in the electricity supply chain.[1] This kind of order with the leader-follower game is characteristic of the electricity market. "?>

In the electricity supply chain, the electricity generator and electricity retailer will make great efforts to improve profits. The electricity generator provides more renewable energy options to attract customers, while the electricity retailer creates more marketing efforts to do the same. For example, in a survey of 3000 Chinese consumers, 97.6% said they were willing to buy renewable energy for their electricity needs, while 90.6% indicated a willingness to pay more for renewable energy.[2] Marketing efforts are made primarily to adjust the demand times of electricity to meet the reasonable electricity consumption requirements with high-quality service. For example, the Guangdong Financial High-Tech Zone, located in the Nanhai District of Foshan, provides high-quality marketing efforts and has attracted more than 260 well-known enterprises, such as Fujitsu's information technology company in Japan and the PICC Southern Information Center. Consequently, Saiyifa Microelectronics Co., Ltd. lost about a half-million dollars in 2017 as the electricity voltage dipped.[3] High-quality services can attract customers, while low-quality services make customers bear the loss.

Consumers' preferences for renewable energy and the marketing efforts to reinforce these preferences drive the electricity supply chain to make corresponding choices. In turn, the government has also introduced carbon regulations to guide the behavior of the electricity supply chain. The cap-and-trade mechanism is the most widely used regulatory method (Li et al. 2018) and includes two forms: grandfathering (Chang et al., 2017) and benchmarking (Zetterberg 2014). Grandfathering uses historical carbon emissions to determine the current carbon quotas. The average of the total carbon emissions in the past 3–5 years is used as the basis for setting the current total carbon quota. Benchmarking sets the carbon

* Corresponding author.
E-mail address: anny78@163.com (Z. Li-Feng).

[1] https://www.scnyw.com/news/general-news/1526.html.

[2] http://www.chinasmartgrid.com.cn/news/20160831/618419.shtml.

[3] http://www.csg.cn/xwzx/2018/gsyw/201806/t20180625_168606.html.

https://doi.org/10.1016/j.spc.2021.08.010
2352-5509/

Nomenclature

Notation	meaning
q	electricity demand
a	potential electricity demand
b	sensitivity coefficient of renewable energy investment
s	sensitivity coefficient of marketing effort investment
d	cost coefficient of renewable energy
g	cost coefficient of marketing effort
e_0	unit carbon quota under the BM
e	initial unit carbon emission
E_0	total carbon quotas under the GM
t	carbon price
π_r	profit of the electricity retailer
π_u	profit of the electricity generator
p	electricity price
w	electricity wholesale price
k	renewable energy investment
f	marketing effort investment

Superscript

N	no cap-and-trade
G	grandfathering
B	benchmarking

Subscript

u	Electricity generator
r	Electricity retailer

unit quota per the industry's net carbon emissions, generally basing this figure on the top 10% of industry enterprises. The basic principle of benchmarking and grandfathering involves artificially building "carbon assets" to internalize the important externality of carbon emission in the energy field, guiding social production activities to green and low-carbon transformation, and promoting the substantial increase of renewable energy investment.

The implementation of cap-and-trade has impacted investments in renewable energy, and both electricity generators and electricity retailers play an important role in these investments. Therefore, their marketing efforts are also affected by cap-and-trade. The main research questions of this paper are as follows:

1 Which mechanism is more conducive to investments in renewable energy and marketing efforts?
2 Which mechanism is more conducive to the increase of electricity demands and the reduction of total carbon emissions?

This paper constructs a two-level electricity supply chain game model to answer the above questions, where the electricity generator is the leader, and the electricity retailer is the follower. This game model assumes two different situations: one using the grandfathering mechanism and another using the benchmarking mechanism. The electricity generator invests in renewable energy, and the electricity retailer invests in marketing efforts. Meanwhile, the electricity retailer purchases electricity from the generator to sell to consumers. Based on the reverse induction, the optimal solution under each carbon regulation is obtained, and comparisons are made between renewable energy investments, marketing efforts, and electricity demands to derive insight.

This paper has three main contributions. First, this paper observes that after the electricity reform, the electricity generator as the leader, such as the China Datang corporation, actively invests in renewable energy, and the electricity retailer as the follower, such as the Sichuan Nengtou electricity sales company, invests in the marketing effort. It also observes that the government has implemented a cap-and-trade regulatory method. Thus, this paper constructs the Stackelberg model based on the phenomenon in reality, which can better explain the impact of cap-and-trade on renewable energy investments and market efforts. Second, although the existing literature has researched renewable energy investment, few papers have considered the cap-and-trade mechanism's impact on renewable energy investments, except for Chen et al. (2021). Moreover, this paper focuses on cap-and-trade within the electricity market and its effects on decision-making regarding renewable energy and marketing efforts, further enriching the research in low-carbon within marketing efforts in the electric power industry. Third, this paper finds that the benchmarking mechanism is more beneficial to the marketing effort investment and more conducive to the renewable energy investment than those under the grandfathering mechanism. This result provides management significance for the government when choosing the cap-and-trade mechanism.

2. Literature review

A wide variety of research has been conducted on the electricity market. This section focuses on three aspects of the extant literature closely related to this study: cap-and-trade mechanisms, renewable energy investment, and marketing efforts.

2.1. Cap-and-trade mechanisms

Many existing studies have provided research on cap-and-trade mechanisms and have mainly focused on inventory, low carbon technology investments, and industry coordination. Regarding inventory, Wang et al. (2018) studied the impact of cap-and-trade mechanisms on the logistics services of fresh food supply chains and found that transfer payment contracts can encourage enterprises to participate in carbon trading. Feng et al. (2020) focused on the problem of joint replenishment among retailers, showing that the retailer with the most altruistic behavior obtained the remaining carbon emissions from other retailers. These papers focused on carbon emissions reduction; however, they did not discuss the renewable energy and marketing effort investments under cap-and-trade mechanisms.

Research on low-carbon technology investments has included work by Du et al. (2013), who considered the construction of an emission-dependent supply chain with a manufacturer and emission-licensing supplier to reduce carbon emissions. Their paper discussed carbon emissions reduction. However, they did not focus on the marketing efforts. This study found that the profit of manufacturers increases with the total carbon quota, while the profit of suppliers decreases with the total carbon quota. Du et al. (2016) studied multi-product joint pricing and production decisions in situations when consumers prefer low-carbon products more than ordinary products. They demonstrated that cap-and-trade could control total carbon emissions and promote the production of low-carbon products. Xu et al. (2017) focused on investing in low-carbon technology and production decisions under cap-and-trade regulations and found that low-carbon technology investments decrease carbon prices and remain unchanged. This paper is different from their paper since it focuses on renewable energy and marketing efforts under cap-and-trade mechanisms. Moreover, renewable energy investment is different from low-carbon investments since low-carbon technology depends on existing equipment, while renewable energy depends on new equipment.

Regarding coordination, Qian et al. (2020) examined the channel coordination between fair retailers in a two-level supply chain and discovered that two-part tariff contracts could only coordinate supply chains partially. Ji et al. (2020) explored production decision-making and ceiling-setting under wholesale prices and revenue-sharing contracts. The results showed that the government's excessive allocation of carbon quotas might damage manufacturers' profits, thus increasing the difficulty of implementing cap-and-trade mechanisms. The above papers have studied cap-and-trade mechanisms from low-carbon technology investments; however, none have discussed the impact of cap-and-trade mechanisms on renewable energy investments, except for Chen et al. (2021).

There are obvious differences between this study and Chen et al. (2021):

1. Their paper considers only a utility firm, which could produce and sell electricity, while this paper considers an electricity supply chain with an electricity generator to produce electricity and an electricity retailer to sell the electricity.
2. Their paper only considers the impact of price on consumer behavior, while this paper further considers the marketing effort, which greatly impacts consumers' electricity consumption.
3. This paper considers the intermittent characteristics of renewable energy.

2.2. Renewable energy investment

The current literature on renewable energy investment includes the pricing and carbon tax (subsidy) mechanisms. For example, Chao (2011) studied the pricing mechanism using the latest economic model to examine the restructured electricity market and considered renewable energy investments under dynamic pricing mechanisms. Results showed that dynamic pricing could increase these investments. Kök et al. (2016) focused on the impact of pricing mechanisms on renewable energy investments and found that peak-pricing produces better investment results than flat-pricing. Their paper discussed the investment of renewable energy. However, the consumers are also concerned about marketing efforts, which is discussed in our study. Moreover, Babich et al. (2020) studied the impact of feed-in tariffs on investments in solar energy and found that when the price of electricity is uncertain, the feed-in tariff mechanism is better for electricity generators as it eliminates price fluctuations. These papers focused on the impact of pricing mechanisms on renewable energy investment. However, this study focuses on the cap-and-trade mechanism. There are essential differences between the two mechanisms; the pricing mechanism guides renewable energy investments by adjusting prices, whereas the cap-and-trade mechanism guides renewable energy investments by influencing carbon prices.

Regarding carbon taxes, He et al. (2012) compared the impact of cap-and-trade mechanisms and carbon tax on renewable energy investments and discovered that carbon tax is more conducive to investments. Kök et al. (2020) focused on the impact of subsidizing traditional energy on renewable energy investments. The results showed that when non-flexible traditional energy is subsidized, investments into renewable energy will increase; conversely, when flexible traditional energy is subsidized, investments into renewable energy will decrease. These pieces of literature have studied the issue of renewable energy investments and carbon regulations. However, they fail to factor in marketing efforts, which could affect the consumers' decisions. As marketing efforts are one of the major results of electricity market-oriented reform, it is important to consider concerning the electricity supply chain.

2.3. Marketing efforts

Marketing efforts have been the subject of inquiries by many scholars, given that this could to create higher demand. Taaffe et al. (2008) constructed a profit-maximization model under conditions of uncertain demands to deal with marketing and procurement decisions. The results showed that a tailored branch-and-bound algorithm approach could provide a solution to this problem. Ma et al. (2013) studied quality and marketing effort decisions under different power structures, demonstrating that the manufacturer would reduce their investment in quality if the retailer were to invest in marketing efforts. Furthermore, Phan et al. (2019b) focused on the corporate social response and marketing effort decision under the vendor-managed inventory model for coordinating. These papers considered the marketing effort. However, they did not focus on the Stackelberg game from the perspective of supply chains. This paper discusses renewable energy and marketing effort investments with the Stackelberg game in the electric power industry.

Dai and Meng (2015) focused on a risk-averse newsvendor model, discovering that marketing efforts could increase consumer demand with the price remaining unchanged. Ranjan and Jha (2019) further studied the dual-channel supply chain for coordinating by considering the marketing efforts. Their results suggest that surplus profit-sharing contracts could increase the supply chain number's profit. Moreover, Ma et al. (2017) focused on concerns of fairness within closed-loop supply chains. They found that the centralization strategy promoted greater marketing efforts. Although their paper discussed marketing efforts, they did not focus on carbon emissions reduction. Carbon emissions reduction is one of the core topics in the field of low carbon. Phan et al. (2019a) investigated situations in which the retailer tries to expand market demand and has less capital relative to the supplier. They found that using trade credit helped coordinate the supply chain. These papers focused on the supply chain within marketing efforts; however, they did not consider the renewable energy investment under cap-and-trade mechanisms to reduce carbon emissions.

The above literature considers the impact of marketing efforts on supply chain operations from the perspectives of algorithms, market power, and coordination; however, they do not consider how carbon-regulation mechanisms may impact these marketing efforts. Our paper further improves the field of marketing by adopting this perspective.

3. Model framework

An electricity generator and electricity retailer form an electricity supply chain in a given region, providing electricity for the market. The government uses the cap-and-trade mechanism to restrict the electricity generator's carbon emissions. Consequently, the electricity generator invests in renewable energy, and the electricity retailer invests in the marketing effort. This framework makes the following specific assumptions:

Assumption 1. It is assumed that consumers' demands for electricity depend not only on the electricity price but also on renewable energy investments and marketing efforts. Without losing generality, this paper draws on the demand function constructed by Liu et al. (2012), Ghosh and Shah (2015), and Xu et al. (2017). The electricity demand function can be represented as follows:

$$q = a - p + b\overline{\theta}k + sf \tag{1}$$

where a is the potential electricity demand p is the electricity price (with a higher p value indicating a lower electricity demand), and k is the renewable energy investment. Further, b $(1 > b > 0)$ is the sensitivity coefficient of renewable energy investment (with a higher b value indicating a greater preference for renewable energy investment), f is the marketing effort, s $(1 > s > 0)$ is the sensitivity coefficient of marketing effort investment (with a higher s value indicating a greater preference for marketing effort), and

θ $(1 > \theta > 0)$ is the random output of renewable energy, where $E(\theta) = \bar{\theta}$.

Assumption 2. The electricity generator invests in renewable energy to increase the electricity demand. The cost function of this renewable energy investment is as follows:

$$G(k) = \frac{1}{2}dk^2 \tag{2}$$

This method of calculating the cost of renewable energy investment has been used in many studies, such as Menanteau et al. (2003) and (Requate 2015). This assumes that an investment in renewable energy is more difficult to make when it is greater and renewable energy is a one-time investment. Additionally, d is the coefficient of the renewable energy investment.

Assumption 3. The electricity retailer invests in marketing efforts to increase the electricity demand. The cost function of this marketing effort investment is as follows:

$$G(q) = \frac{1}{2}gf^2 \tag{3}$$

Similarly, this method of calculating marketing effort investments has been used in many studies, such as Ma et al. (2013) and Phan et al. (2019b). g is the coefficient of the marketing effort investment, with a higher g value indicating a lower investment coefficient.

Assumption 4. The use of traditional energy creates a certain amount of carbon emissions related to historic energy demands and carbon emission units. Therefore, we suppose that the total carbon emissions function is as follows:

$$E^M = e\left(q - \bar{\theta}k\right) \tag{4}$$

where e represents the units of carbon emissions from traditional energy, and $q - \bar{\theta}k$ is the conventional energy demand. When e or $q - \bar{\theta}k$ are higher, there are more total carbon emissions.

Assumption 5. It is assumed that the electricity retailer makes purchases from electricity generators with wholesale price w, and then sells them to consumers with price p. The electricity generator has a buy/sell carbon quota with carbon price t. In addition, we ensure that the negative definite of Hessian matrix and the optimal value are greater than zero with the following assumptions: $2g - s^2 > 0, d > \frac{gb^2\theta^2}{2(2g-s^2)}, b\bar{\theta}^2 < d$, and $be\bar{\theta}^2 - de + de_0 < 0$. These assumptions are similar to those used in studies by Ji et al. (2017) and Chen et al. (2021).

4. Model analysis

Three models are analyzed in this section, representing the use of the no cap-and-trade mechanism, grandfathering mechanism, or benchmarking mechanism. We first drew the optimal solutions from the no cap-and-trade mechanism. In the following models, superscript $M = \{N, G, B\}$ indicates the above mechanisms (no cap-and-trade, grandfathering, and benchmarking, respectively). The superscript * indicates the optimal solution, and subscript $\{u, r\}$ indicates the electricity generator and electricity retailer, respectively.

4.1. No cap-and-trade mechanism

Under the no cap-and-trade mechanism $(M = N)$, there is no need for the electricity supply chain members to bear the cost of carbon emissions. The electricity generator first decides the electricity price (w^N) and renewable energy investment (k^N). Following this, the electricity retailer decides the electricity price (p^N) and marketing effort (h^N) to maximize profits. Thus, the profit of the electricity generator and electricity retailer is as follows:

$$E\left(\pi_u^N\right) = wq^N - c\left(q^N - \bar{\theta}k^N\right) - \frac{1}{2}d(k^N)^2 \tag{5}$$

$$E\left(\pi_r^N\right) = \left(p^N - w^N\right)q^N - \frac{1}{2}g(f^N)^2 \tag{6}$$

In Eq. (5), the first term is the electricity generator's income from selling the electricity to the electricity retailer, while the second term is the cost of the renewable energy investment. In Eq. (6), the first term is the electricity retailer's income from selling the electricity to the consumer, while the second term is the cost of the marketing effort investment. According to the reverse induction method, the electricity generator makes decisions on electricity price and marketing effort. Let $\frac{\partial E(\pi_r^N)}{\partial p^N} = 0$ and $\frac{\partial E(\pi_r^N)}{\partial p^N} = 0$. It is possible to represent the optimal electricity price p^{N*} and marketing effort investment f^{N*} as follows:

$$p^{N*} = \frac{ag + gw - s^2 w + bg\bar{\theta}k^N}{2g - s^2} \tag{7}$$

$$f^{N*} = \frac{as - sw + b\bar{\theta}k^N s}{2g - s^2} \tag{8}$$

When substituting Eqs. (7), (8) into Eq. (5), the electricity generator decides the electricity wholesale price (w^N) and renewable energy investment (k^N). Let $\frac{\partial E(\pi_u^N)}{\partial w^N} = 0$ and $\frac{\partial E(\pi_u^N)}{\partial k^N} = 0$, where the optimal electricity wholesale price w^{N*} and renewable energy investment k^{N*} are as follows:

$$k^{N*} = \frac{\left[abg + (4 - b)cg - 2cs^2\right]\bar{\theta}}{2d\left(2g - s^2\right) - gb^2\bar{\theta}^2} \tag{9}$$

$$w^{N*} = \frac{d(a + c)\left(2g - s^2\right) - bc\bar{\theta}^2\left[(2 - b)g - s^2\right]}{2d\left(2g - s^2\right) - gb^2\bar{\theta}^2} \tag{10}$$

Substituting Eqs. (9), (10) into Eqs. (7), (8) provides the optimal electricity price p^{N*} and marketing effort investment f^{N*}, as shown below:

$$p^{N*} = \frac{(3a + c)dg - (a + c)ds^2 - bc\bar{\theta}^2\left[(b - 3)g + s^2\right]}{2d\left(2g - s^2\right) - gb^2\bar{\theta}^2} \tag{11}$$

$$f^{N*} = \frac{s\left(ad - cd + bc\bar{\theta}^2\right)}{2d\left(2g - s^2\right) - gb^2\bar{\theta}^2} \tag{12}$$

Finally, when substituting Eqs. (9), (12) into Eq. (1) and Eqs. (4), (6), the optimal electricity demand q^{N*}, total carbon emissions E^{N*}, and profits of supply chain's members (π_r^{N*}, π_u^{N*}) are as follows:

$$q^{N*} = \frac{g\left(ad - cd + bc\bar{\theta}^2\right)}{2d\left(2g - s^2\right) - gb^2\bar{\theta}^2} \tag{13}$$

$$E^{N*} = \frac{e\left\{(a - c)dg - \bar{\theta}^2\left\{abg + 2c\left[(2 - b)g - s^2\right]\right\}\right\}}{2d\left(2g - s^2\right) - gb^2\bar{\theta}^2} \tag{14}$$

$$\pi_u^{N*} = \frac{\left\{g\bar{\theta}^2\left[(4 - 2b)c^2 + 2abc\right] + (a + c)^2 dg - 2c^2 s^2\bar{\theta}^2\right\}}{2\left[2d\left(2g - s^2\right) - gb^2\bar{\theta}^2\right]} \tag{15}$$

$$\pi_r^{N*} = \frac{g\left(2g - s^2\right)\left(bc\bar{\theta} + ad - cd\right)^2}{2\left[2d\left(2g - s^2\right) - gb^2\bar{\theta}^2\right]^2} \tag{16}$$

Proposition 1. Under the no cap-and-trade mechanisms, the optimal renewable energy investment k^{N*}, electricity wholesale price w^{N*}, electricity price p^{N*}, marketing effort f^{N*}, electricity demand q^{N*}, total carbon emissions E^{N*}, and the profits of the supply chains members (π_r^{N*}, π_u^{N*}) are shown by Eqs. (6), (16), respectively.

4.2. Grandfathering mechanism

Under the grandfathering mechanism ($M = G$), the electricity supply chain members need to bear the cost of carbon emissions and obtain the total carbon quotas E_0. The electricity generator first decides the electricity price (w^G) and renewable energy investment (k^G). Following this, the electricity retailer decides the electricity price (p^G) and marketing effort (f^G) to maximize profits. Thus, the profits of the electricity generator and electricity retailer are as follows:

$$E\left(\pi_u^G\right) = w^G q^G - c\left(q^G - \overline{\theta} k^G\right) - \frac{1}{2} d (k^G)^2 + t\left[E_0 - e\left(q^G - \overline{\theta} k^G\right)\right] \quad (17)$$

$$E\left(\pi_r^G\right) = \left(p^G - w^G\right) q^G - \frac{1}{2} g (f^G)^2 \quad (18)$$

In Eq. (17), the first term is the electricity generator's income from selling the electricity to the electricity retailer. Meanwhile, the second term is the cost of the renewable energy investment, and the last term is the carbon cost (i.e., $E_0 < e(q^G - \theta k^G)$). In Eq. (18), the first term is the electricity retailer's income from selling the electricity to the consumer, and the second term is the cost of the marketing effort investment. According to the reverse induction method, the electricity generator makes decisions on the electricity price and marketing efforts. Let $\frac{\partial E(\pi_r^G)}{\partial p^G} = 0$ and $\frac{\partial E(\pi_r^G)}{\partial f^G} = 0$. Thus, the optimal electricity price $p^{G*}$and marketing effort investment h^{G*} are as follows:

$$p^{G*} = \frac{ag + gw^G - s^2 w^G + bgk^G \overline{\theta}}{2g - s^2} \quad (19)$$

$$f^{G*} = \frac{s\left(a - w^G + b\overline{\theta} k^G\right)}{2g - s^2} \quad (20)$$

When substituting Eqs. (19), (20) into Eq. (17), the electricity generator decides the electricity wholesale price (w^G) and renewable energy investment (k^G). Let $\frac{\partial E(\pi_u^G)}{\partial w^G} = 0$ and $\frac{\partial E(\pi_u^G)}{\partial k^G} = 0$, where the optimal electricity wholesale price $w^{G*}$and renewable energy investment k^{G*} are as follows:

$$w^{G*} = \frac{d(a + c + et)\left(2g - s^2\right) - b(c + et)\left[(-2 + b)g + s^2\right]\overline{\theta}^2}{2d\left(2g - s^2\right) - gb^2\overline{\theta}^2} \quad (21)$$

$$k^{G*} = \frac{\overline{\theta}\left\{abg + (c + et)\left[(4 - b)g - 2s^2\right]\right\}}{2d\left(2g - s^2\right) - gb^2\overline{\theta}^2} \quad (22)$$

Substituting Eqs. (21), (22) into Eqs. (19), (20) provides the optimal electricity price $p^{G*}$and marketing effort investment f^{G*}, as shown below:

$$p^{G*} = \frac{ad\left(3g - s^2\right) + (c + et)\left\{d\left(g - s^2\right) + b\overline{\theta}^2\left[(3 - b)g - s^2\right]\right\}}{2d\left(2g - s^2\right) - gb^2\overline{\theta}^2} \quad (23)$$

$$f^{G*} = \frac{ads - s(c + et)\left(d - b\overline{\theta}^2\right)}{2d\left(2g - s^2\right) - gb^2\overline{\theta}^2} \quad (24)$$

Finally, when substituting Eqs. (21), (24) into Eqs. (1), (4), and (17), (18), the optimal electricity demand q^{G*}, total carbon emissions E^{G*}, and the profits of the supply chain members (π_r^{G*}, π_u^{G*}) are as follows:

$$q^{G*} = \frac{g\left[ad - (c + et)\left(d - b\overline{\theta}^2\right)\right]}{2d\left(2g - s^2\right) - gb^2\overline{\theta}^2} \quad (25)$$

$$E^{G*} = \frac{e\left\{ag\left(d - b\theta^2\right) - (c + et)\left[dg + 2\left((2 - b)g - s^2\right)\theta^2\right]\right\}}{2d\left(2g - s^2\right) - b^2 g\theta^2} \quad (26)$$

$$\pi_r^{G*} = \frac{g\left(2g - s^2\right)\left[ad - (c + et)\left(d - b\overline{\theta}^2\right)\right]^2}{2\left[2d\left(2g - s^2\right) - gb^2\theta^2\right]^2} \quad (27)$$

$$\pi_u^{G*} = E_0 t + \frac{\left\{\begin{array}{c} dg(a - c)^2 - 2adegt + 2cdegt + de^2gt^2 - 2c^2\overline{\theta}^2\left[(-2 + b)g + s^2\right] \\ -4cet\overline{\theta}^2\left[(-2 + b)g + s^2\right] + 2e^2t^2\overline{\theta}^2\left[(2 - b)g - s^2\right] + 2abg(c + et)\overline{\theta}^2 \end{array}\right\}}{2\left[2d\left(2g - s^2\right) - gb^2\overline{\theta}^2\right]} \quad (28)$$

Proposition 2. Under grandfathering mechanisms, the optimal renewable energy investment k^{G*}, electricity wholesale price w^{G*}, electricity price p^{G*}, marketing effort f^{G*}, electricity demand q^{G*}, total carbon emissions E^{G*}, and profits of the supply chain members (π_r^{G*}, π_u^{G*}) are shown by Eqs. (21), (28), respectively.

4.3. Benchmarking mechanism

Under the benchmarking mechanism ($M = B$), the electricity supply chain members must bear the cost of unit carbon emission, which is higher than the unit carbon quota. The electricity generator first decides the electricity price (w^B) and renewable energy investment (k^B). Following this, the electricity retailer decides the electricity price (p^B) and marketing effort (f^B) to maximize profits. Thus, the profits of the electricity generator and electricity retailer are as follows:

$$E\left(\pi_u^B\right) = w^B q^B - c\left(q^B - \overline{\theta} k^B\right) - \frac{1}{2} d (k^B)^2 + t\left[e_0 q - e\left(q^B - \overline{\theta} k^B\right)\right] \quad (29)$$

$$E\left(\pi_r^B\right) = \left(p^B - w^B\right) q^B - \frac{1}{2} g (f^B)^2 \quad (30)$$

In Eq. (29), the first term is the electricity generator's income from selling the electricity to the electricity retailer, the second term is the cost of the renewable energy investment, and the last term is the carbon cost (i.e., $e_0 q < e(q^B - \theta k^B)$). From Eq. (30), the first term is the electricity retailer's income from selling the electricity to the consumer, and the second term is the cost of the marketing effort investment. According to the reverse induction method, the electricity generator makes decisions on electricity price and marketing efforts. Let $\frac{\partial E(\pi_r^B)}{\partial p^B} = 0$ and $\frac{\partial E(\pi_r^B)}{\partial f^B} = 0$. Thus, the optimal electricity price p^{B*} and marketing effort investment h^{B*} are as follows:

$$p^{B*} = \frac{ag + gw^B - s^2 w^B + bgk^B \overline{\theta}}{2g - s^2} \quad (31)$$

$$f^{B*} = \frac{s\left(a - w^B + b\overline{\theta} k^B\right)}{2g - s^2} \quad (32)$$

When substituting Eqs. (31), (32) into Eq. (29), the electricity generator decides the electricity wholesale price (w^B) and renewable energy investment (k^B). Let $\frac{\partial E(\pi_u^B)}{\partial w^B} = 0$ and $\frac{\partial E(\pi_u^B)}{\partial k^B} = 0$, where the optimal electricity wholesale price $w^{G*}$and renewable energy investment k^{B*} are as follows:

$$w^{B*} = \frac{\left\{\begin{matrix} d\left(2g-s^2\right)(a+c+et)+b(c+et)\left[(2-b)g-s^2\right]\overline{\theta}^2 \\ +te_0\left[d\left(-2g+s^2\right)+gb^2\overline{\theta}^2\right]\end{matrix}\right\}}{2d\left(2g-s^2\right)-gb^2\overline{\theta}^2} \quad (33)$$

$$k^{B*} = \frac{\overline{\theta}\left\{abg+\left[(4-b)g-2s^2\right](c+et)+bgte_0\right\}}{2d\left(2g-s^2\right)-gb^2\overline{\theta}^2} \quad (34)$$

When substituting Eqs. (33). (34) into Eqs. (31), (32), the optimal electricity price p^{B*} and marketing effort investment f^{B*} are as follows:

$$p^{B*} = \frac{\left\{\begin{matrix} (c+et)\left\{d\left(g-s^2\right)+b\overline{\theta}^2\left[(3-b)g-s^2\right]\right\} \\ +ad\left(3g-s^2\right)-te_0\left[d\left(g-s^2\right)-gb^2\overline{\theta}^2\right]\end{matrix}\right\}}{2d\left(2g-s^2\right)-gb^2\overline{\theta}^2} \quad (35)$$

$$f^{B*} = \frac{s\left[ad-(c+et)\left(d-b\overline{\theta}^2\right)+dte_0\right]}{2d\left(2g-s^2\right)-gb^2\overline{\theta}^2} \quad (36)$$

Finally, when substituting Eqs. (33), (36) into Eqs. (1), (4), and (31), (32), the optimal electricity demand q^{B*}, total carbon emissions E^{B*}, and profits of the supply chain members (π_r^{B*}, π_u^{B*}) are as follows:

$$q^{B*} = \frac{g\left[ad-(c+et)\left(d-b\overline{\theta}^2\right)+dte_0\right]}{2d\left(2g-s^2\right)-gb^2\overline{\theta}^2} \quad (37)$$

$$E^{B*} = \frac{e\left\{\begin{matrix} (c+et)\left\{-dg+2\overline{\theta}^2\left[(-2+b)g+s^2\right]\right\} \\ +ag\left(d-b\overline{\theta}^2\right)+gt\left(d-b\overline{\theta}^2\right)e_0\end{matrix}\right\}}{2d\left(2g-s^2\right)-gb^2\overline{\theta}^2} \quad (38)$$

$$\pi_r^{B*} = \frac{g\left(2g-s^2\right)\left[ad-(c+et)\left(d-b\overline{\theta}^2\right)+dte_0\right]^2}{2\left[2d\left(2g-s^2\right)-gb^2\overline{\theta}^2\right]^2} \quad (39)$$

$$\pi_u^{B*} = \frac{\left\{\begin{matrix} 2(c+et)\left\{abg+(c+et)\left[(2-b)g-s^2\right]\right\}\overline{\theta}^2 \\ +dg(a-c-et)^2+gte_0\left[2ad-2(c+et)\left(d-b\overline{\theta}^2\right)+dte_0\right]\end{matrix}\right\}}{2\left[2d\left(2g-s^2\right)-gb^2\overline{\theta}^2\right]} \quad (40)$$

Proposition 3. Under benchmarking mechanisms, the optimal renewable energy investment k^{B*}, electricity wholesale price w^{B*}, electricity price p^{B*}, marketing effort f^{B*}, electricity demand q^{B*}, total carbon emissions E^{B*}, and profits of the supply chain members (π_r^{B*}, π_u^{B*}) are shown by Eqs. (33), (40), respectively.

5. Model comparison

Corollary 1. *The impact of the carbon price on the profit of the electricity supply chain members is as follows:* $\frac{\partial \pi_r^{G*}}{\partial t} < 0$, $\frac{\partial \pi_u^{G*}}{\partial t} < 0$; $\frac{\partial \pi_r^{B*}}{\partial t} < 0$, $\frac{\partial \pi_u^{B*}}{\partial t} < 0$.

Corollary 1 analyzes the impact of the carbon price on the total profit. The results show that the profit decreases as the carbon price increases. The increase of the carbon price means that the electricity generator's carbon emission costs have increased, reducing their profit. found that an increase in the carbon tax would hurt the manufacturer's profit, similar to the conclusion of this study. Therefore, the government should set a reasonable carbon price (carbon tax).

Moreover, the electricity generator would transfer these costs to the electricity retailer, reducing the electricity retailer's profit. This suggests that a higher carbon price within the carbon trade market would hurt the enthusiasm of the electricity supply chain members. The electricity supply chain managers realize that increasing carbon prices would reduce the profits of all supply chain members and affect the production enthusiasm of the enterprise. Therefore, managers should pay more attention to the carbon price. It suggests that, first, it generates more efficient units and less inefficient units through dispatching improvement. Second, it further increases the proportion of renewable energy.

Proposition 4. *Comparing renewable energy investments among three carbon regulation mechanisms, the order is as follows:* $k^{N*} < k^{G*} < k^{B*}$.

Proposition 4: compares renewable energy investments among three carbon regulation mechanisms, with the results showing that $k^{N*} < k^{G*} < k^{B*}$. The implementation of the cap-and-trade mechanism prompts the electricity retailer to invest in more renewable energy.

Implementing cap-and-trade mechanisms would encourage the electricity generator to invest more in renewable energy. For example, from 2010 to 2019, China ranked first for a renewable energy investment of USD 758 billion under the cap-and-trade mechanism.[4] EU has invested in renewable energy of about EUR 10.5 billion from 2009 to 2013 under cap-and-trade mechanisms (He et al., 2019). Moreover, by the end of 2020, the renewable energy investment installed capacity of state power groups China Datang corporation and Huaneng Group accounted for 56.09%, 38.20%, and 36.5%, respectively.[5] This suggests that the implementation of cap-and-trade mechanisms is conducive to renewable energy investment, one of the reasons for implementing this mechanism. The electricity supply chain enterprises should promptly adjust the energy structure, given that the cap-and-trade mechanism would increase the renewable energy investment.

Additionally, the benchmarking mechanism is more beneficial for the renewable energy investment than the grandfathering mechanism. Under benchmarking, the firms obtain a quota of carbon units from their renewable energy investments, while they do not receive the same incentive under grandfathering. This suggests that the benchmarking mechanism is better than grandfathering mechanism to promote investment in renewable energy. The renewable energy investment is also related to energy-resource structure, which encourages the further development of sustainable energy. From the energy-resource structure perspective, benchmarking may present a suitable opportunity.

Proposition 5. *Comparing marketing effort investments among three carbon regulation mechanisms, the order is as follows:* $f^{G*} < f^{B*} < f^{N*}$.

Proposition 5: compares marketing effort investments among three carbon regulation mechanisms, with results showing that $f^{G*} < f^{B*} < f^{N*}$. The implementation of cap-and-trade prevents the electricity retailer from creating marketing efforts, and their overall costs are reduced when this investment does not need to be made. The electricity retailer observes that the electricity generator invests in renewable energy to increase the electricity demand under cap-and-trade. Therefore, the electricity retailer is motivated to reduce their marketing efforts since it would not cause an excessive reduction in demand and reduces their overall expenditure.

[4] https://www.163.com/dy/article/EODEI20A05369WVE.html.
[5] https://www.163.com/dy/article/G9SLH86C0511E624.html.

It suggests that the government should be aware that the implementation of the cap-and-trade mechanism may damage market investment efforts by the electricity retailer. From the perspective of marketing efforts, it is best to adopt the no cap-and-trade mechanism.

Moreover, compared with the grandfathering mechanism, the benchmarking mechanism encourages the electricity retailer to invest more in marketing efforts. The electricity retailer bears less electricity wholesale costs under the benchmarking mechanism ($w^{G*} < w^{B*}$) and has more capital to invest in marketing efforts. Retailers are willing to invest in marketing efforts but not without the funds to do so. From the perspective of the supply chain, the benchmarking mechanism provides an appropriate solution.

Notably, a situation with the no cap-and-trade mechanism has the greatest positive effect on the marketing effort; therefore, this may be a suitable choice for increasing marketing effort investment. The benchmarking mechanism encourages the electricity generator to invest more in renewable energy and reduces limited marketing effort investment. If a situation without cap-and-trade is not possible, the government can consider using benchmarking to improve the electricity market.

Proposition 6. *Comparing the electricity demand among three carbon regulation mechanisms, the order is as follow:* $q^{G*} < q^{B*} < q^{N*}$.

Proposition 6: compares the electricity demand among three carbon regulation mechanisms, with results showing that $q^{G*} < q^{B*} < q^{N*}$. The implementation of cap-and-trade mechanisms would decrease the consumer's electricity demand. Implementing the cap-and-trade mechanism would increase the renewable energy investment while decreasing the marketing efforts. Ultimately, the demand for electricity will be reduced. It suggests that the cap-and-trade mechanism may harm the increases in the electricity demand. The government should be aware of this problem and reduced such negative effects. From the perspective of renewable energy investment, it is best to adopt cap-and-trade mechanisms.

When comparing the grandfathering and benchmarking mechanisms, it is clear that benchmarking produces more electricity output. The benchmarking mechanism promotes electricity generators' investments in renewable energy and encourages electricity retailers to invest more in marketing efforts than those under the grandfathering mechanism. Under the benchmarking mechanism, electricity generation can obtain part of the unit carbon quota to reduce carbon emission costs.

The benchmarking mechanism would produce less electricity demand than that under the no cap-and-trade mechanism. However, the adoption of the benchmarking mechanism by the government may be a better choice for the development of the electricity market scale. Moreover, the electricity supply chain's enterprises should be aware that the cap-and-trade mechanisms impact its output.

Proposition 7. *Comparing the total carbon emissions among three carbon regulation mechanisms, the order is as follows:* $E^{G*}<E^{B*}<E^{N*}$.

Proposition 7: compares the total carbon emissions among three carbon regulation mechanisms, with results showing that $E^{G*} < E^{B*} < E^{N*}$. The cap-and-trade mechanism is beneficial for reducing carbon emissions. More investments in renewable energy occur under cap-and-trade to reduce total carbon emissions, implying that this mechanism is effective. Investing more in renewable energy could replace more traditional energy, the main source of carbon emissions. It suggests that the government could implement the cap-and-trade mechanism to reduce carbon emissions. Reducing carbon emissions is conducive to sustainable development. From the perspective of carbon emissions, it is best to adopt the no cap-and-trade mechanism.

Further, grandfathering sees a greater reduction in the total carbon emissions than benchmarking. Fewer conventional energy sources are used under the grandfathering mechanism, leading to less carbon emission. This suggests that if the government seeks to control total carbon emissions more effectively, the implementation of the grandfathering mechanism is a viable option. Moreover, the benchmarking mechanism is conducive to renewable energy. Thus, the government prefers the benchmarking mechanism to invest in renewable energy. In short, the grandfathering mechanism could control carbon emissions, while the benchmarking mechanism is conducive to invest in renewable energy.

6. Numerical analysis

In this section, a numerical analysis is used to discuss the three models. Parameters are designated to verify the results and highlight potential new management insights. The reverse induction method is elaborated on in detail in the process of the theoretical solution. This section is based on the equilibrium solution to further show the influence of parameters on the equilibrium solution. We select parameters from the electricity industry reports[6] (Xuan, 2019; Nanjing daily, 2019). The parameters are as follows: $a = 10(GW)$, $b = 0.8(GW)$, $c = 0.18(\$/kwh)$, $\overline{\theta} = 0.3$, $e = 0.84(kg/kwh)$,$s = 0.9(\$/GW)$, $t = 1.5(\&/kg)$, $E_0 = 1.4(M)$, $e_0 = 0.3(kg)$.

6.1. Cost coefficient of renewable energy investment

Fig. 1 shows the impact of the coefficient of renewable energy investment on the electricity supply chain under different cap-and-trade mechanisms and setting $g = 2(\$/GW)$, $d \in [0.5, 1.5]$. The main results are provided as follows.

Fig. 1a and b demonstrate that marketing effort investments and the price of electricity decrease with the cost coefficient of renewable energy. Intuitively speaking, an increase in the cost of renewable energy would inevitably reduce one's willingness to invest in it. The electricity demand would be reduced due to the preference of consumers for renewable energy sources. The electricity retailer adopts comprehensive measures to encourage the demand to increase once more, such as reducing the price of electricity and cutting the marketing effort investments. Reducing electricity prices serves to maintain market share due to consumers' price sensitivity. Meanwhile, cutting marketing efforts reduces the retailer's investment costs. It implies that the increase of the coefficient of renewable energy investment has an impact on the electricity price and a restraining effect on marketing efforts.

Furthermore, Fig. 1a shows that adopting cap-and-trade mechanisms is not conducive to marketing effort investments, which verifies the result of proposition 5. It suggests that, from the perspective of marketing efforts, enterprises prefer the no cap-and-trade mechanism. In addition, Fig. 1b shows that implementing cap-and-trade mechanisms forces the electricity retailer to increase electricity prices since the electricity generator should bear the cost of carbon emissions. The electricity price decreases with the cost coefficient of renewable energy, given that the electricity supply chain would decrease the electricity price to attract the electricity demand. It suggests that the consumers would prefer the no cap-and-trade mechanism from the electricity price perspective.

Fig. 1c shows that total carbon emissions increase with the cost coefficient of renewable energy. In this situation, investments in renewable energy decrease, leading to total carbon emissions increasing. For example, the global investment in renewable energy decreased by 7% in 2017, the highest in 15 years, and carbon emis-

[6] http://www.tanpaifang.com/jienenjianpai/2019/0809/65094.html.

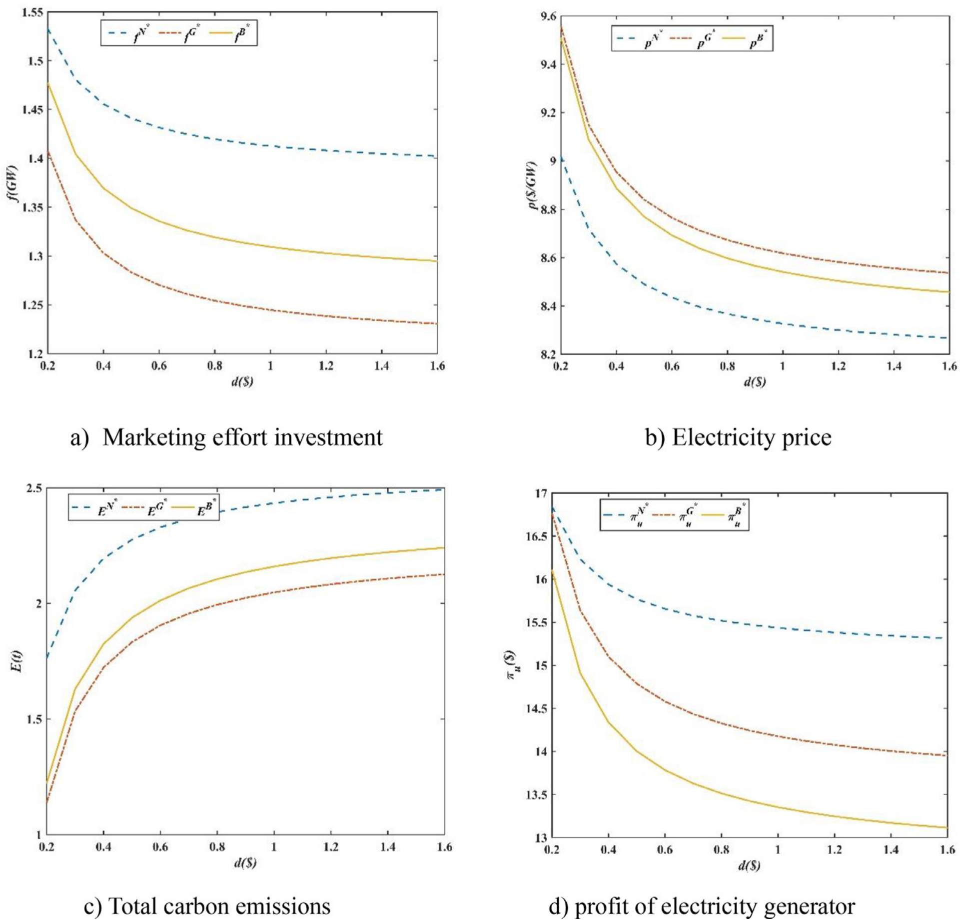

Fig. 1. Impact of coefficient renewable energy investment on electricity supply chain. (a) Marketing effort investment . (b) Electricity price. (c) Total carbon emissions. (d) profit of electricity generator

sions increased by 3%.[7] This implies that the government should encourage enterprises to reduce the cost coefficient of renewable energy, providing a new perspective on the reduction of carbon emissions. In addition, implementing cap-and-trade could also reduce total carbon emissions, implying that this mechanism is effective. It suggests that the government should adopt the grandfathering mechanism to reduce the total carbon emissions.

Fig. 1d shows that the electricity generator's profit decreases with the coefficient of renewable energy investment. When the electricity generator bears more of the cost of renewable energy investment, it cannot make as much profit. Furthermore, the implementation of the cap-and-trade mechanism would also erode the profits of electricity generators since it holds them responsible for the cost of carbon emissions. This suggests that reducing the cost coefficient of renewable energy would increase the marketing efforts and electricity generator's profit and reduce the total carbon emissions. Moreover, the electricity generator prefers the no cap-and-trade mechanism to gain more profits. The government should consider the profit of electricity generation when implementing cap-and-trade mechanisms.

6.2. Cost coefficient of marketing effort investment

Fig. 2 shows the impact of the coefficient of marketing effort investment on the electricity supply chain under different cap-and-trade mechanisms and setting $d = 1(\$/GW)$, $g \in [1, 3]$. The main results are as follows.

Fig. 2a and b suggest that investments in renewable energy investment and the price of electricity both decrease with the coefficient of marketing effort investments. An increase in the cost of marketing efforts would inevitably reduce the willingness of the electricity retailer to invest in them, leading to a reduction in the demand for electricity. The electricity retailer takes measures to reduce prices to mitigate the impact of this reduced demand on the market. Subsequently, the electricity generator reduces its investment in renewable energy due to making less of a profit. The electricity retailer reduces the investment cost of marketing efforts for renewable energy investments, providing a new perspective for investing in renewable energy. The government should guide enterprises to increase investment in marketing efforts to reduce the cost coefficient. Additionally, Fig. 2a demonstrates that the cap-and-trade mechanism is profitable for investments in renewable energy, and the benchmarking mechanism is more profitable than the grandfathering mechanism. Therefore, the government should ideally adopt benchmarking to encourage investments in renewable energy. Fig. 2b also shows that electricity prices are higher under cap-and-trade since the electricity supply chain needs to bear the cost of carbon emissions.

Fig. 2c provides that the total carbon emissions decrease along with the cost coefficient of marketing effort. This is because investments in renewable energy could cause traditional energy sources to be replaced. Therefore, the total carbon emissions would be reduced. Cap-and-trade could further reduce total carbon emissions while using the benchmarking mechanism would reduce carbon emissions to an even greater degree. Notably, reducing the cost coefficient of marketing efforts is conducive to the improve-

[7] https://t.qianzhan.com/caijing/detail/180815-66f88818.html.

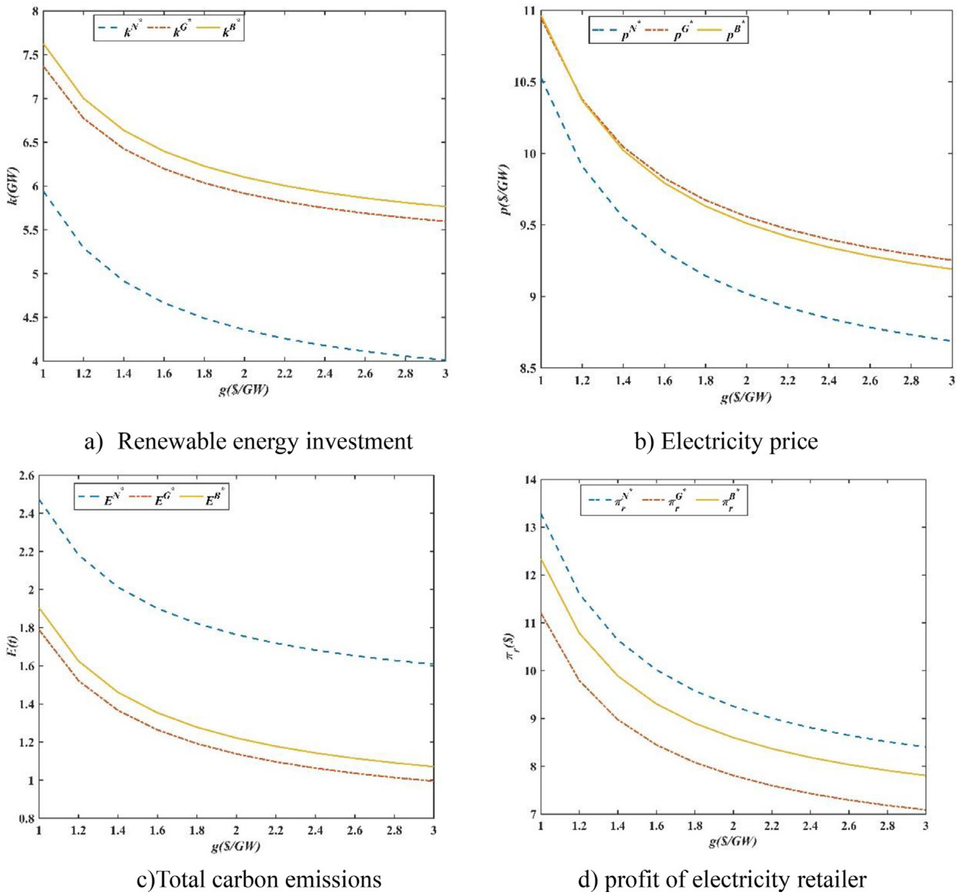

Fig. 2. Impact of coefficient marketing effort investment on electricity supply chain. (a) Renewable energy investment. (b) Electricity price. (c)Total carbon emissions. (d) profit of electricity retailer

ment of market efforts, but it will also increase the total carbon emissions.

Fig. 2d demonstrates that the profit of the electricity retailer decreases with the coefficient of marketing effort investments. When the cost of marketing efforts increases, it erodes the electricity retailer's profits. Electricity retailers would also obtain less profit under cap-and-trade mechanisms. This suggests that reducing the cost coefficient of renewable energy would increase marketing efforts and the electricity retailer's profit and reduce total carbon emissions. Moreover, the electricity retailer prefers the no cap-and-trade mechanism. The government should consider the profit of the electricity retailer when implementing cap-and-trade mechanisms.

7. Discussion

This paper discusses the impact of cap-and-trade mechanisms on renewable energy investment considering marketing efforts. Based on this, the game model is constructed in this paper. On the one hand, a two-level electricity supply chain with a leader's electricity generator and a follower's electricity retailer is close to real life, and it better describes the real situation. On the other hand, it draws some enlightening conclusions for managers through a more general theoretical model for reality.

For the electricity supply chain, reducing the cost coefficient of renewable energy would increase the investment of renewable energy and the profit of supply chain enterprises. Second, the electricity generator prefers benchmarking to invest in renewable energy since benchmarking would bear part of the costs of carbon emissions. Finally, the electricity retailer is more inclined to invest in market efforts with the no cap-and-trade mechanism, implying that implementing the cap-and-trade mechanism would reduce the electricity retailer's marketing efforts.

First, the government should actively guide electricity supply chain enterprises to reduce the cost coefficient and invest more in renewable energy. For example, from 2009 to 2019, solar energy costs have fallen by 89%, and the investment cost of renewable energy will further decrease in the world.[8] Second, the government should realize the balance between investment in renewable energy and carbon emission reduction. Benchmarking invests more in renewable energy, while grandfathering generates fewer carbon emissions. Finally, the government is more inclined to grandfathering since most electricity is sold to the consumer market.

8. Conclusion

Facing the energy market reform, both the electricity generator and electricity retailer try to maximize their profits. The electricity generator invests in renewable energy to increase diversification. Meanwhile, the electricity retailer invests in the marketing effort to expand the market scale. At the same time, the government adopts the cap-and-trade mechanism, affecting both the renewable energy and marketing effort investments. Under these circumstances, the impacts of the grandfathering mechanism and benchmarking mechanism are compared as they relate to investment behavior, electricity demand, and total carbon emissions.

The primary results are summarized as follows. First, both the grandfathering mechanism and benchmarking mechanism encour-

8 https://baijiahao.baidu.com/s?id=1685514802056428456&wfr=spider&for=pc%EF%BC%9Bhttps://guangfu.bjx.com.cn/news/20210701/1161530.shtml.

age investments in renewable energy, with benchmarking being more conducive to the investment. Second, only the benchmarking mechanism positively affects investment in marketing efforts; grandfathering is not conducive to this type of investment. Third, both the grandfathering mechanism and benchmarking mechanism are conducive to the improvement of market demand; however, grandfathering produces higher carbon emissions, while the benchmarking mechanism reduces them. Finally, investment in marketing efforts decreases with the cost coefficient of renewable energy, and investment in renewable energy decreases with the cost coefficient of marketing effort.

This paper researches investments in renewable energy and market efforts under the framework of the electricity supply chain. Its findings suggest some areas worthy of further study. First, this paper considered the electricity generator-dominated supply chain. Further studies may seek to explore supply chains where the electricity retailer is dominant. Second, this paper considers only the single cycle. Expanding the research to multiple cycles would increase its applicability. Third, this paper considers only the cap-and-trade carbon emission reduction strategy, leaving both the carbon tax and renewable portfolio standard methods to be the subject of future work.

Declaration of competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix

Proof of Corollary 1

With 1-3 propositions, we have, $\frac{\partial \pi_r^{G*}}{\partial t} = -\frac{eg(2g-s^2)(d-b\bar{\theta}^2)[ad-et(d-b\bar{\theta}^2)]}{[2d(2g-s^2)-b^2g\bar{\theta}^2]^2} < 0$, $\frac{\partial \pi_u^{G*}}{\partial t} = \frac{-a(deg-beg\bar{\theta}^2)+de^2gt-2e^2t\bar{\theta}^2[(-2+b)g+s^2]}{4dg-2ds^2-b^2g\bar{\theta}^2} + E_0 < 0$, $\frac{\partial \pi_r^{B*}}{\partial t} = -\frac{g(2g-s^2)(de-be\bar{\theta}^2-de_0)[ad-et(d-b\bar{\theta}^2)+dte_0]}{[2d(2g-s^2)-b^2g\bar{\theta}^2]^2} < 0$, and $\frac{\partial \pi_u^{B*}}{\partial t} =$

$$\frac{\left\{\begin{array}{c}-a(deg-beg\bar{\theta}^2-dge_0)-2te^2\bar{\theta}^2[(-2+b)g+s^2]\\ -2egte_0(d-b\bar{\theta}^2)+dgte_0^2+dgte^2\end{array}\right\}}{4dg-2ds^2-b^2g\bar{\theta}^2} < 0.$$

Proof of Proposition 4

With Propositions 1–3, we have, $k^{N*}-k^{B*} = -\frac{t\bar{\theta}(2e(2g-s^2)+bg(e_0-e))}{4dg-2ds^2-gb^2\bar{\theta}^2} < 0$, $k^{G*}-k^{B*} = -\frac{be_0gt\bar{\theta}}{4dg-2ds^2-gb^2\bar{\theta}^2} < 0$, and $k^{N*}-k^{G*} = -\frac{et\bar{\theta}(2(2g-s^2)-bg)}{4dg-2ds^2-gb^2\bar{\theta}^2} < 0$. Thus, $k^{N*} < k^{G*} < k^{B*}$.

Proof of Proposition 5

With propositions 1–3, we have, $f^{N*}-f^{B*} = -\frac{st(e(d-b\theta^2)-de_0)}{2d(-2g+s^2)+b^2g\theta^2} > 0$, $f^{G*}-f^{B*} = \frac{-de_0st}{4dg-2ds^2-gb^2\bar{\theta}^2} < 0$, and $f^{N*}-f^{G*} = -\frac{est(b\bar{\theta}^2-d)}{4dg-2ds^2-gb^2\bar{\theta}^2} > 0$. Thus, $f^{G*} < f^{B*} < f^{N*}$.

Proof of the Proposition 6

With the Propositions 1–3, we have, $q^{N*}-q^{B*} = -\frac{gt(be\bar{\theta}^2-de+de_0)}{4dg-2ds^2-gb^2\bar{\theta}^2} > 0$, $q^{G*}-q^{B*} = -\frac{de_0gt}{4dg-2ds^2-gb^2\bar{\theta}^2} < 0$, and $q^{N*}-q^{G*} = \frac{egt(-b\bar{\theta}^2+d)}{4dg-2ds^2-gb^2\bar{\theta}^2} > 0$. Thus, $q^{N*} < q^{B*} < q^{G*}$.

Proof of the Proposition 7

With the Propositions 1–3, we have, $E^{N*}-E^{B*} = \frac{et(deg-2e((-2+b)g+s^2)\theta^2+g(-d+b\theta^2)e_0)}{2d(2g-s^2)-b^2g\theta^2} > 0$, $E^{G*}-E^{B*} = -\frac{ee_0gt(d-b\bar{\theta}^2)}{4dg-2ds^2-gb^2\bar{\theta}^2} < 0$, and $E^{N*}-E^{G*} = -e^2t\frac{2s^2\bar{\theta}^2-dg-4g\bar{\theta}^2+2bg\bar{\theta}^2}{4dg-2ds^2-gb^2\bar{\theta}^2} > 0$. Thus, $E^{G*} < E^{B*} < E^{N*}$.

References

Babich, V., Lobel, R., Yücel, Ş., 2020. Promoting solar panel investments: feed-in-tariff vs. tax-rebate policies. Manuf. Serv. Oper. Manag. 22 (6), 1148–1164.

Chang, X.Y., Li, Y.P., Zhao, Y.B., Liu, W.J., Wu, J., 2017. Effects of carbon permits allocation methods on remanufacturing production decisions. J. Clean. Prod. 152, 281–294.

Chao, H., 2011. Efficient pricing and investment in electricity markets with intermittent resources. Energy Policy 39 (7), 3945–3953.

Chen, W., Chen, J., Ma, Y., 2021. Renewable energy investment and carbon emissions under cap-and-trade mechanisms. J. Clean. Prod. 278, 123341.

Dai, J., Meng, W., 2015. A risk-averse newsvendor model under marketing-dependency and price-dependency. Int. J. Prod. Eco. 160, 220–229.

Du, S., Zhu, L., Liang, L., Ma, F., 2013. Emission-dependent supply chain and environment-policy-making in the 'cap-and-trade'system. Energy Policy 57, 61–67.

Du, S., Tang, W., Song, M., 2016. Low-carbon production with low-carbon premium in cap-and-trade regulation. J. Clean. Prod. 134, 652–662.

Fang, D., Zhao, C., Yu, Q., 2018. Government regulation of renewable energy generation and transmission in China's electricity market. Renew. Sustain. Energy Rev. 93, 775–793.

Feng, H., Zeng, Y., Cai, X., Qian, Q., Zhou, Y., 2020. Altruistic profit allocation rules for joint replenishment with carbon cap-and-trade policy. Eur. J. Oper. Res. 290 (3), 956–967.

Ghosh, D., Shah, J., 2015. Supply chain analysis under green sensitive consumer demand and cost sharing contract. Int. Prod. Econ. (164) 319–329.

He, Y., Wang, L., Wang, J., 2012. Cap-and-trade vs. carbon taxes: a quantitative comparison from a generation expansion planning perspective. Comput. Ind. Eng. 63 (3), 708–716.

He, L., Zhang, L., Zhong, Z., Wang, D., Wang, F., 2019. Green credit, renewable energy investment and green economy development: empirical analysis based on 150 listed companies of China. J. Clean. Prod. 208 (20), 363–372.

Ji, T., Xu, X., Yan, X., Yu, Y., 2020. The production decisions and cap setting with wholesale price and revenue sharing contracts under cap-and-trade regulation. Int. J. Prod. Res. 58 (1), 128–147.

Ji, J., Zhang, Z., Yang, L., 2017. Comparisons of initial carbon allowance allocation rules in an O2O retail supply chain with the cap-and-trade regulation. Int. J. Prod. Econ. 187, 68–84.

Kök, A.G., Shang, K., Yücel, Ş., 2016. Impact of electricity pricing policies on renewable energy investments and carbon emissions. Manag. Sci. 64 (1), 131–148.

Kök, A., Kevin, S., Şafak, Y., 2020. Investments in renewable and conventional energy: the role of operational flexibility. Manuf. Servi. Oper. Manag. 22 (5), 925–941.

Li, G., Zheng, H., Ji, X., Li, H., 2018. Game theoretical analysis of firms' operational low-carbon strategy under various cap-and-trade mechanisms. J. Clean. Prod. 197, 124–133.

Liu, Z., Anderson, T., Cruz, J.M., 2012. Consumer environmental awareness and competition in two-stage supply chains. Eur. J. Oper. Res. 218 (3), 602–613.

Ma, P., Li, K.W., Wang, Z.J., 2017. Pricing decisions in closed-loop supply chains with marketing effort and fairness concerns. Int. J. Prod. Res. 55 (22), 6710–6731.

Ma, P., Wang, H., Shang, J., 2013. Supply chain channel strategies with quality and marketing effort-dependent demand. Int. J. Prod. Econ. 144 (2), 572–581.

Menanteau, P., Finon, D., Lamy, M.L., 2003. Prices versus quantities: choosing policies for promoting the development of renewable energy. Energy Policy 31 (8), 799–812.

Phan, D.A., Vo, T.L.H., Lai, A.N., 2019a. Supply chain coordination under trade credit and retailer effort. Int. J. Prod. Res. 57 (9), 2642–2655.

Phan, D.A., Vo, T.L.H., Lai, A.N., Nguyen, T.L.A., 2019b. Coordinating contracts for VMI systems under manufacturer-CSR and retailer-marketing efforts. Int. J. Prod. Econ. 211, 98–118.

Qian, X., Chan, F.T.S., Zhang, J., Yin, M., Zhang, Q., 2020. Channel coordination of a two-echelon sustainable supply chain with a fair-minded retailer under cap-and-trade regulation. J. Clean. Prod. 244, 118715.

Requate, T., 2015. Green tradable certificates versus feed-in tariffs in the promotion of renewable energy shares. Environ. Econ. Policy Stud. 17 (2), 211–239.

Taaffe, K., Geunes, J., Romeijn, H.E., 2008. Target market selection and marketing effort under uncertainty: the selective newsvendor. Eur. J. Oper. Res. 189 (3), 987–1003.

Wang, M., Zhao, L., Herty, M., 2018. Modelling carbon trading and refrigerated logistics services within a fresh food supply chain under carbon cap-and-trade regulation. Int. J. Prod. Res. 56 (12), 4207–4422.

Xu, X., He, P., Xu, H., Zhang, Q., 2017. Supply chain coordination with green technology under cap-and-trade regulation. Int. J. Prod. Econ. 183, 433–442.

Xuan X. The carbon dioxide emission intensity of thermal power is about 841 g /kWh. http://www.tanpaifang.com/jienenjianpai/2019/0809/65094.html. Accessed August 09, 2019.

Ranjan, A., Jha, J.K., 2019. Pricing and coordination strategies of a dual-channel supply chain considering green quality and sales effort. J. Clean. Prod. 218, 409–424.

Zetterberg, L., 2014. Benchmarking in the European union emissions trading system: abatement incentives. Energy Econ. 43, 218–224.